EE 1402 HIGH VOLTAGE ENGINEERING

Unit 5

TESTS OF INSULATORS

- Type Test To Check The Design Features
- Routine Test To Check The Quality Of The Individual Test Piece.
- High Voltage Tests Include

  (i) Power frequency tests

  (ii) Impulse tests

TESTS OF INSULATORS

POWER FREQUENCY TESTS

(a) Dry and wet flashover tests:

- a.c voltage of power frequency is applied across the insulator and increased at a uniform rate of 2% per second of 75%of ther estimated test voltage.
- If the test is conducted under normal conditions without any rain – dry flashover test.
- If the test is conducted under normal conditions of rain –wet flashover test

(b) Dry and wet withstand tests(one minute)

The test piece should withstand the specified voltage which is applied under dry or wet conditions.

IMPULSE TESTS ON INSULATORS

- **Impulse withstand voltage test:**

  If the test object has withstood the subsequent applications of standard impulse voltage then it is passed the test

- **Impulse flashover test:**

  The average value between 40% and 60% failure is taken, then the insulator surface should not be damaged.

- **Pollution Testing:**

  Pollution causes corrosion ,deterioration of the material, partial discharges and radio interference. Salt fog test is done.

TESTING OF BUSHINGS

Power frequency tests

(a) Power Factor-Voltage Test:

- Set up as in service or immersed in oil.
- Conductor to HV and tank to earth.
- Voltage is applied up to the line value in increasing steps and then reduced.
- The capacitance and power factor are recorded in each step.

(b) Internal or Partial discharge Test:

- To find the deterioration or failure due to internal discharges
- Conducted using partial discharge arrangements
- Performance is observed from voltage Vs discharge magnitude.
- It is a routine test.

(c) Momentary Withstand Test at Power frequency

- Based on IS:2009
- The bushing has to withstand the applied test voltage without flashover or puncture for 30 sec.

TESTING OF BUSHINGS

(d) One Minute withstand Test at Power Frequency

- Most common & routine test
- Test is carried in dry &wet for one minute.
- In wet test, rain arrangement is mounted as in service.
- Properly designed bushing should withstand without flashover for one minute.

(e) Visible Discharge Test at Power Frequency

- Conducted based on IS:2009
- Conducted to determine radio interference during service
- Conducted in dark room
- Should not be any visible discharges other than arcing horns/ guard rings.

TESTING OF BUSHINGS

Impulse voltage tests:

- **Full wave Withstand Test**
  - The bushing is tested for either polarity voltages
  - Five consecutive full wave is applied
  - If two of them flashed over, then 10 additional applications are done.
  - If the test object has withstood the subsequent applications of standard impulse voltage then it is passed the test.
- **Chopper Wave withstand Test**
  - Sometimes done on HV bushings (220kV, 400kV and above)
  - Switching surge flashover test is included for HV bushings.
  - This is also carried out same as above full wave test.

TESTING OF BUSHINGS

Temperature Rise and Thermal Stability Tests

- To observe the temperature rise and to ensure that it doesn't go into 'thermal runaway' condition.
- Temperature rise test is done at ambient temperature (below 40^0C) at a rated power frequency.
- The steady temperature rise should not exceed 45^0C.
- Test is carried out for long time & increase in temperature is less than 1^0C/hr.
- This test is enough to produce large dielectric loss and thermal in stability.
- **Thermal stability test** is done for bushing rated for 132 kV above.
- Carried out on the bushing immersed in oil at max. service temperature with 86% of normal system voltage.
- This is a type test for low rating and routine test for high ratings.

TESTING OF ISOLATORS AND CIRCUIT BREAKERS

Isolator:

- Off-load or minimum current breaking mechanical switch.
- Explained according to "IS:9921 Part-1, 1981".
- Interrupting small currents(0.5A): Capacitive currents of bushings, busbars etc.,

Circuit Breaker:

- Onload or high current breaking switch

Testing of Circuit Breaker:

- To evalute,
  - Constructional & operating characteristics
  - Electrical characteristics

TESTING OF ISOLATORS AND CIRCUIT BREAKERS

Electrical Characteristics:

- Arcing voltage
- Current chopping characteristics
- Residual currents
- Rate of decrease of conductance of the arc space and the plasma
- Shunting effects in interruption

Physical Characteristics:

- Arc extinguishing medium
- Pressure developed at the point of interruption
- Speed of contact travelling
- Number of breaks
- Size of the arcing chamber
- Material and configuration of the circuit interruption

TESTING OF ISOLATORS AND CIRCUIT BREAKERS

Circuit Characteristics:

- Degree of electrical loading
- Applied voltage
- Type of fault
- Time of interruption
- Frequency
- Power factor
- Rate of rise of recovery voltage
- Re-stricking voltage
- Decrease in AC component of the short circuit current
- DC component of the short circuit current

TESTING OF ISOLATORS AND CIRCUIT BREAKERS

- **Dielectric tests:**
  - Consists of over voltage withstand tests of power frequency, lightning and switching impulse voltages
  - Tested for internal & external insulation with CB in both the open & closed position.
  - Voltage in Open position >15% of that of closed position.
  - During test, CB is mounted on insulators above ground to avoid ground flash over.
- **Impulse tests:**
  - Impulse test and switching surge tests with switching over voltage are done.

TESTING OF ISOLATORS AND CIRCUIT BREAKERS

- **Thermal tests:**
  - To check the thermal behaviour of the breakers
  - Rated current through all three phases of the switchgear is passed continuously for a period long enough to achieve steady state conditions
  - Temperature rise must not exceed 40°C when the rated normal current is less than 800 amps and 50°C if it is 800 amps and above
  - Contact resistances between the isolating contacts and between the moving and fixed contacts is important. These points are generally the main sources of excessive heat generation.

TESTING OF ISOLATORS AND CIRCUIT BREAKERS

- **Mechanical Test:**
  - To ensure the open and closing with out mechanical failure
  - It requires 500(some times 20,000) operations without failure and with no adjustment of the mechanism.
  - A resulting change in the material or dimensions of a particular component may considerably improve the life and efficiency of the mechanism.

TESTING OF ISOLATORS AND CIRCUIT BREAKERS

Short circuit tests:

- To check the ability to safely interrupt the fault currents.
- To determine the making and breaking capacities at different load currents
- Methods of conducting short circuit tests,
  1. Direct tests
     1. Using the power utility system as the source.
     2. Using a short circuit generator as the source
  2. Synthetic Tests

TESTING OF ISOLATORS AND CIRCUIT BREAKERS

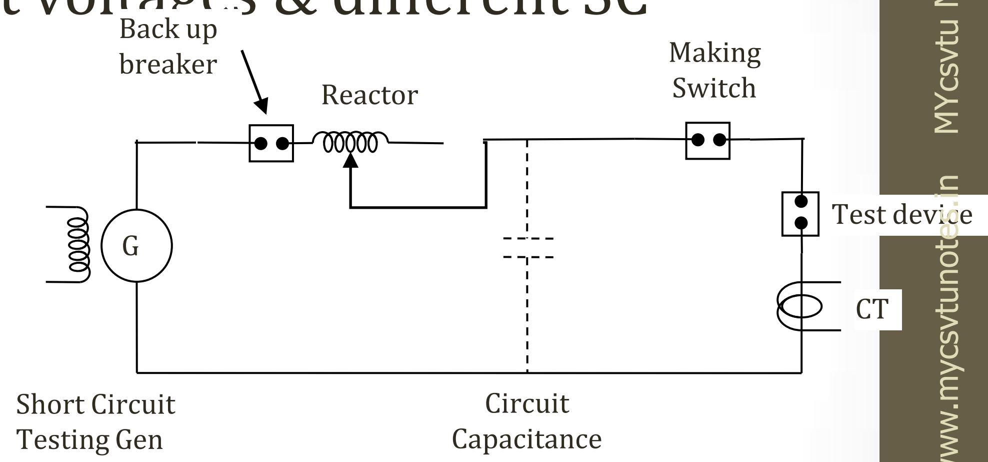
Direct tests -Using the power utility system as the source:

- To check the ability to make or break in normal load conditions or short circuit conditions in the network itself
- Done during limited energy consumption
- Advantages:
  1. Tested under actual conditions in a network
  2. Special cases (like breaking of charging current of long lines, very short line faults etc.,) can be tested
  3. Thermal & dynamic effects of short circuit currents and applications of safety devices can be studied
- Disadvantages:
  1. Can be tested only in rated voltage and capacity of the network
  2. Test is only at light load conditions
  3. Inconvenience and expensive installation of control and measuring equipment is required in the field.

TESTING OF ISOLATORS AND CIRCUIT BREAKERS

Direct Testing-Short circuit test in laboratories:

- To test the CBs at different voltages & different SC currents
- The setup consists of,
  - A SC generator
  - Master CB
  - Resistors
  - Reactors and
  - Measuring devices

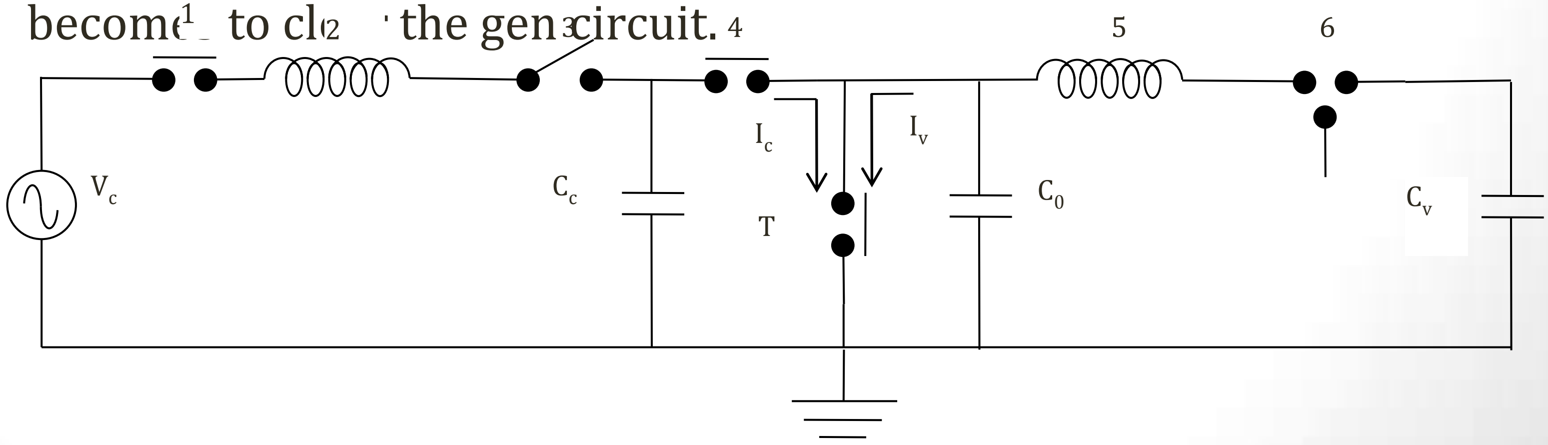


- The make switch initiates the circuit short circuit & master switch isolates the test device from the source at the end of predetermined time.
- If the test device failed to operate, master CB can be

TESTING OF ISOLATORS AND CIRCUIT BREAKERS

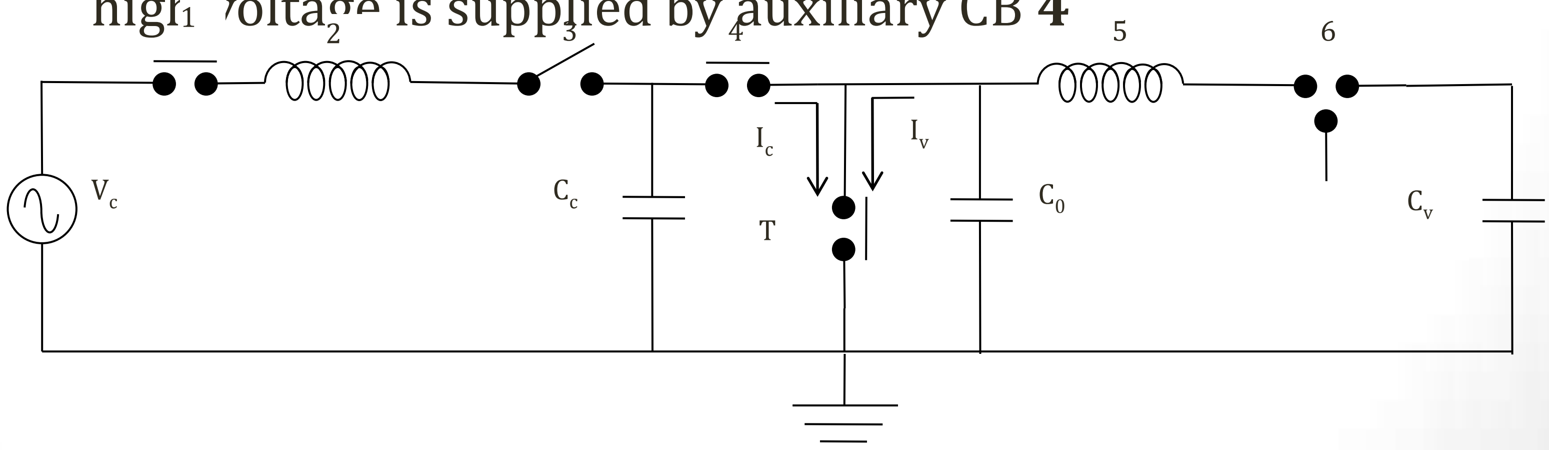
Synthetic Testing of CBs:

- Heavy current at low voltage is applied
- Recovery voltage is simulated by high voltage, small current source
- Procedure:
  - Auxiliary breaker **3** and test circuit breaker **T** closed, making switch **1** is closed. ∴ Current flows through test CB.
  - At time t_0, the test CB begins to open and the master breaker **1** becomes to close the gen circuit.



TESTING OF ISOLATORS AND CIRCUIT BREAKERS

- At time t_1, just before zero of the gen current, the trigger gap **6** closes and high frequency current from capacitance $\mathbf{C_v}$ flows through the arc of the gap
- At time $\mathbf{t_2}$, gen current is zero. Master CB **1** is opened
- The current from $\mathbf{C_v}$ will flow through test CB and full voltage will be available
- At the instant of breaking, the source is disconnected and high voltage is supplied by auxiliary CB **4**



TESTING OF CABLES

Different tests on cables are

i. Mechanical tests like bending test,dripping and drainage test, and fire resistance and corrosion tests
ii. Thermal duty tests
iii. Dielectric power factor tests
iv. Power frequency withstand voltage tests
v. Impulse withstand voltage tests
vi. Partial discharge test
vii. Life expectancy tests

TESTING OF CABLES

Dielectric power factor tests:

- Done using HV Schering Bridge
- The p.f or dissipation factor ‘tanδ’ is measured at 0.5, 1.0, 1.66 and 2.0 times the rated phase-to-ground voltage of the cable
- Max. value of p.f and difference in p.f b/w rated voltage and 1.66 times of rated voltage is specified.
- The difference between the rated voltage and 2.0 times of rated voltage is also specified
- A choke is used in series with the cable to form a resonant circuit.
- This improves the power factor and rises the test voltage b/w the cable core and the sheath to the required value when a HV and high capacity source is used.

TESTING OF CABLES

High voltage testing on Cables:

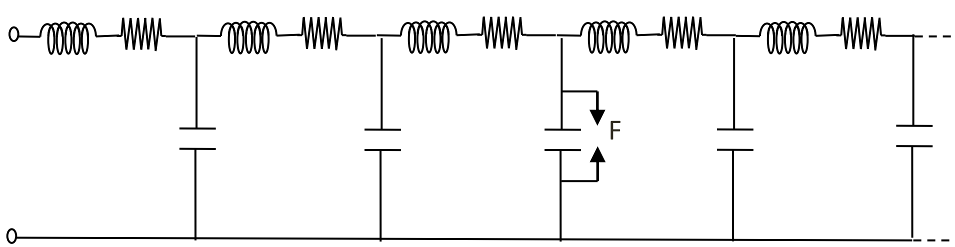
- Power frequency HV A.C, DC and impulse voltages are applied to test the withstanding capability
- Continuity is checked with high voltage at the time of manufacturing
- **Routine test:**
  - Cable should withstand 2.5 times of the rated voltage for 10 mins without damage in insulation
- **Type test:**
  - Done on samples with HVDC & impulses
  - DC Test:1.8 times of the rated voltage (-ve) applied for 30 mins.
  - Impulse Test: 1.2/50μS wave applied. Cable should withstand 5 consecutive impulses without any damage
  - After impulse test, power frequency & power factor test is

TESTING OF CABLES

Partial Discharge test:

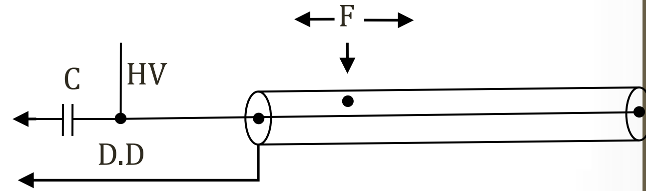
i. Discharge measurement:

- Life time of insulation depends on the internal discharges. So, PD measurement is important.
- In this test, weakness of insulation or faults can be detected
- Fig(i) and (ii) shows the connection to discharge detector through coupling capacitor.

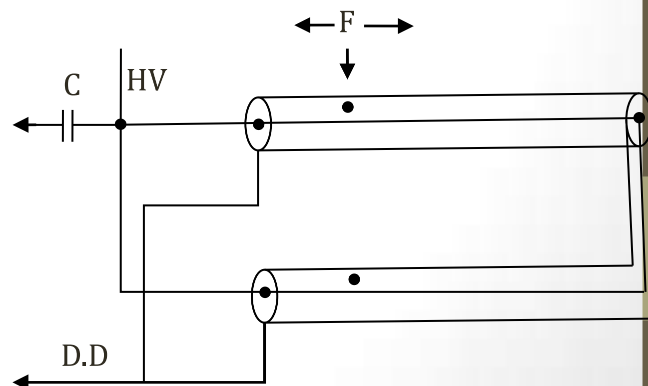


Equivalent Circuit of Cable for discharges

(i)



(ii)



TESTING OF CABLES

- If the coupling capacitor connected, transient wave will be received directly from the discharge cavity and second wave from the wave end i.e., two transient pulses is detected
- In circuit shown in fig (ii), no severe reflection is occurred except a second order effect of negligible magnitude.
- Two transients arrive at both ends of the cable-super imposition of the two pulses detected-give serious error in measurement of discharge

ii. Location of discharges

  - Voltage dip caused by discharge or fault is travelled along the length & determined at the ends
  - Time duration b/w the consecutive pulses can be determined
  - The shape of the voltage gives information on the nature of discharges

TESTING OF CABLES

iii. Scanning Method:

- Cable is passed through high electric field and discharge location is identified.
- Cable core is passed through a tube of insulating material filled with distilled water
- Four ring electrodes (two @ ends+two @ middle) mounted in contact with water.
- Middle electrode given to HV. If a discharge occurs in the portion b/w the middle electrodes, as the cable is passed b/w the middle electrode's portion, the discharge is detected and located at the length of cable.

iv. Life Test

- For reliability studies in service.
- Accelerated life tests conducted with increased voltages to determine the expected life time.

$$E_m = K t^{\left(\frac{1}{n}\right)}$$

- K-Constant depends on Field condition and material
- n- Life index depends on material

TESTING OF TRANSFORMERS

- Transformer is one of the most expensive and important equipment in power system.
- If it is not suitably designed its failure may cause a lengthy and costly outage.
- Therefore, it is very important to be cautious while designing its insulation, so that it can withstand transient over voltage both due to switching and lightning.
- The high voltage testing of transformers is, therefore, very important and would be discussed here. Other tests like temperature rise, short circuit, open circuit etc. are not considered here.
- However,these can be found in the relevant standard specification.

TESTING OF TRANSFORMERS

- Induced over voltage test:
  - Transformer secondary is excited by HFAC(100 to 400Hz) to about twice the rated voltage
  - This reduces the core saturation and also limits the charging current necessary in large X-mer
  - The insulation withstand strength can also be checked
- Partial Discharge test:
  - To assess the magnitude of discharges
  - Transformer is connected as a test specimen and the discharge measurements are made
  - Location and severity of fault is ascertained using the travelling wave theory technique
  - Measurements are to be made at all the terminals of the transformer
  - Insulation should be so designed that the discharge measurement should be much below the value of 10^4 pC.

TESTING OF TRANSFORMERS

Impulse Testing of Transformer:

- To determine the ability of the insulation to withstand transient voltages
- In short rise time of impulses, the voltage distribution along the winding will not be uniform
- The equivalent circuit of the transformer winding for impuls

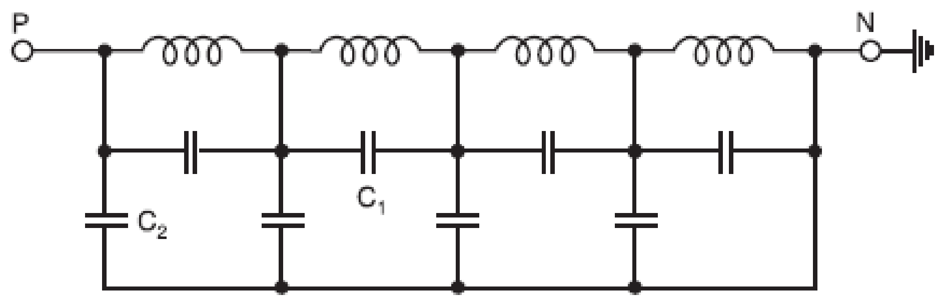


Fig.1: Equivalent circuit of a transformer for impulse voltage

TESTING OF TRANSFORMERS

- Impulse voltage applied to the equivalent sets up uneven voltage distribution and oscillatory voltage higher than the applied voltage
- Impulse tests:
  - Full wave standard impulse
  - Chopped wave standard impulse (Chopping time: 3 to 6μS)
- The winding which is not subjected to test are short circuited and connected to ground
- Short circuiting reduces the impedance of transformer and hence create problems in adjusting the standard waveshape of impulse generators

TESTING OF TRANSFORMERS

Procedure for Impulse Test:

- The schematic diagram of the transformer connection for impulse

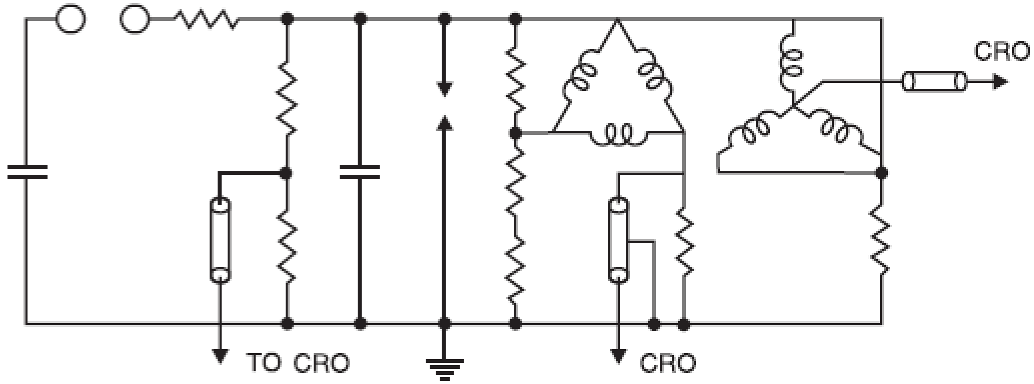


Fig.2: Arrangement for Impulse test of transformer

- The voltage and current waveforms are recorded during test. Sometimes, the transferred voltage in secondary and neutral current are also recorded.

TESTING OF TRANSFORMERS

Impulse testing consists of the following steps:

1. *Application of impulse of magnitude 75% of the Basic Impulse Level (BIL) of the transformer* under test.
2. *One full wave of 100% of BIL.*
3. *Two chopped wave of 115% of BIL.*
4. *One full wave of 100% BIL and*
5. *One full wave of 75% of BIL.*

- During impulse testing the fault can be located by general observation like noise in the tank or smoke or bubble in the breather.
- If there is a fault, it appears on the Oscilloscope as a partial or complete collapse of the applied voltage.
- Study of the wave form of the neutral current also indicated the type of fault.

TESTING OF TRANSFORMERS

- If an arc occurs between the turns or from turn to the ground, a train of high frequency pulses are seen on the oscilloscope and wave shape of impulse changes.
- If it is only a partial discharge, high frequency oscillations are observed but no change in wave shape occurs.
- Impulse strength of the transformer winding is same for either polarity of wave whereas the flash over voltage for bushing is different for different polarity.

TESTING OF SURGE DIVERTERS

(i) Power frequency spark over test

- It is a routine test.
- The test is conducted using a series resistance to limit the current in case a spark over occurs.
- It has to withstand 1.5 times the rated value of the voltage for 5 successive applications.
- Test is done under both dry and wet conditions.

(ii) 100% standard impulse spark over test

- This test is conducted to ensure that the diverter operates positively when over voltage of impulse nature occur.
- The test is done with both positive and negative polarity waveforms.
- The magnitude of the voltage at which 100% flashover occurs is the required spark over voltage.

TESTING OF SURGE DIVERTERS

(iii) Residual voltage test:

- This test is conducted on pro-rated diverters of ratings in the range 3 to 12 kV only.
- Standard impulse wave of 1/50μS is applied, voltage across it is recorded.
- Magnitude of the current ≈ 2 X Rated current
- A graph is drawn b/w current magnitude and voltage across pro-rated unit and residual voltage is calculated
- V_1=rating of the complete unit
- V_2=rating of the prorated unit tested
- V_{R1}=residual voltage of the complete unit
- V_{R2}=residual voltage of the prorated unit
- $V_1/V_2= V_{R1}/ V_{R2}$
- $V_1/= V_2 .(V_{R1}/ V_{R2})$
- Let, V_{RM} – Max. permissible residual voltage of the unit

  Multiplying factor, r = (V_{RM} /V_1)

  Diverter is said to be passed when $V_{R2}<rV_2$

TESTING OF SURGE DIVERTERS

HIGH CURRENT IMPULSE TEST ON SURGE DIVERTERS

- Impulse current wave of 4/10μS is applied to pro-rated arrester in the range of 3 to 12kV.
- Test is repeated for 2 times
- Arrester is allowed to cool to room temperature

The unit is said to pass the test if

i. The power frequency sparkover voltage before and after the test does not differ by more than 10%

ii. The voltage and current waveforms of the diverter do not differ in the 2 applications

iii. The non linear resistance elements do not show any puncture or flashover

TESTING OF SURGE DIVERTERS

Other tests are

i. Mechanical tests like porosity test, temperature cycle tests
ii. Pressure relief test
iii. voltage withstand test on the insulator housing
iv. the switching surge flashover test
v. the pollution test

INSULATION CO-ORDINATION

Insulation Coordination:

"The process of bringing the insulation strengths of electrical equipment and buses into the proper relationship with expected overvoltages and with the characteristics of the insulating media and surge protective devices to obtain an acceptable risk of failure."

Basic lightning impulse insulation level (BIL):

"The electrical strength of insulation expressed in terms of the crest value of a standard lightning impulse under standard atmospheric conditions."

Basic switching impulse insulation level (BSL)

"The electrical strength of insulation expressed in terms of the crest value of a standard switching impulse."

INSULATION CO-ORDINATION

Factor of Earthing:

This is the ratio of the highest r.m.s. phase-to-earth power frequency voltage on a sound phase during an earth fault to the r.m.s. phase-to-phase power frequency voltage which would be obtained at the selected location without the fault.

This ratio characterizes, in general terms, the earthing conditions of a system as viewed from the selected fault location.

Effectively Earthed System :

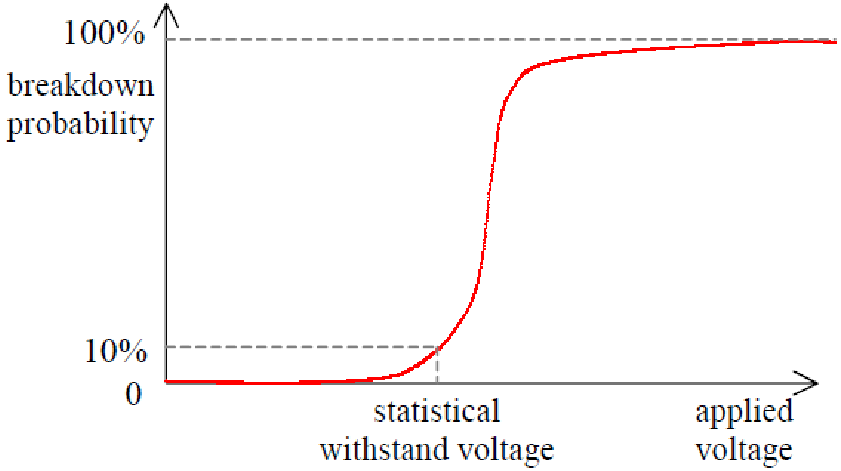
A system is said to be effectively earthed if the factor of earthing does not exceed 80%, and non-effectively earthed if it does.

INSULATION CO-ORDINATION

Statistical Impulse Withstand Voltage:

This is the peak value of a switching or lightning impulse test voltage at which insulation exhibits, under the specified conditions, a 90% probability of withstand.

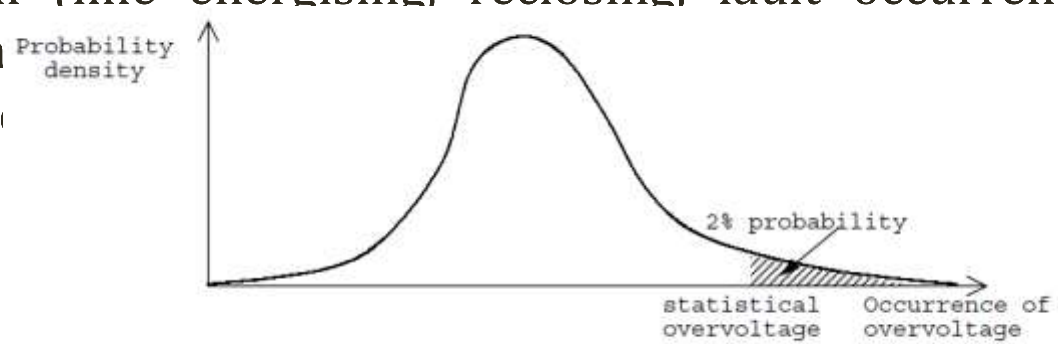
In practice, there is no 100% probability of withstand voltage. Thus the value chose   down.



INSULATION CO-ORDINATION

Statistical Impulse Voltage:

This is the switching or lightning overvoltage applied to equipment as a result of an event of one specific type on the system (line energising, reclosing, fault occurrence, lightning discha … obability of being …



Protective Level of Protective Device:

These are the highest peak voltage value which should not be exceeded at the terminals of a protective device when switching impulses and lightning impulses of standard shape and rate values are applied under specific conditions.

INSULATION CO-ORDINATION

Necessity of Insulation Coordination:

i. To ensure the reliability & continuity of service
ii. To minimize the number of failures due to over voltages
iii. To minimize the cost of design, installation and operation

Requirements of Protective Devices:

- Should not usually flash over for power frequency overvoltages
- Volt-time characteristics of the device must lie below the withstand voltage of the protected apparatus
- Should be capable of discharging high energies in surges & recover insulation strength quickly
- Should not allow power frequency follow-on current

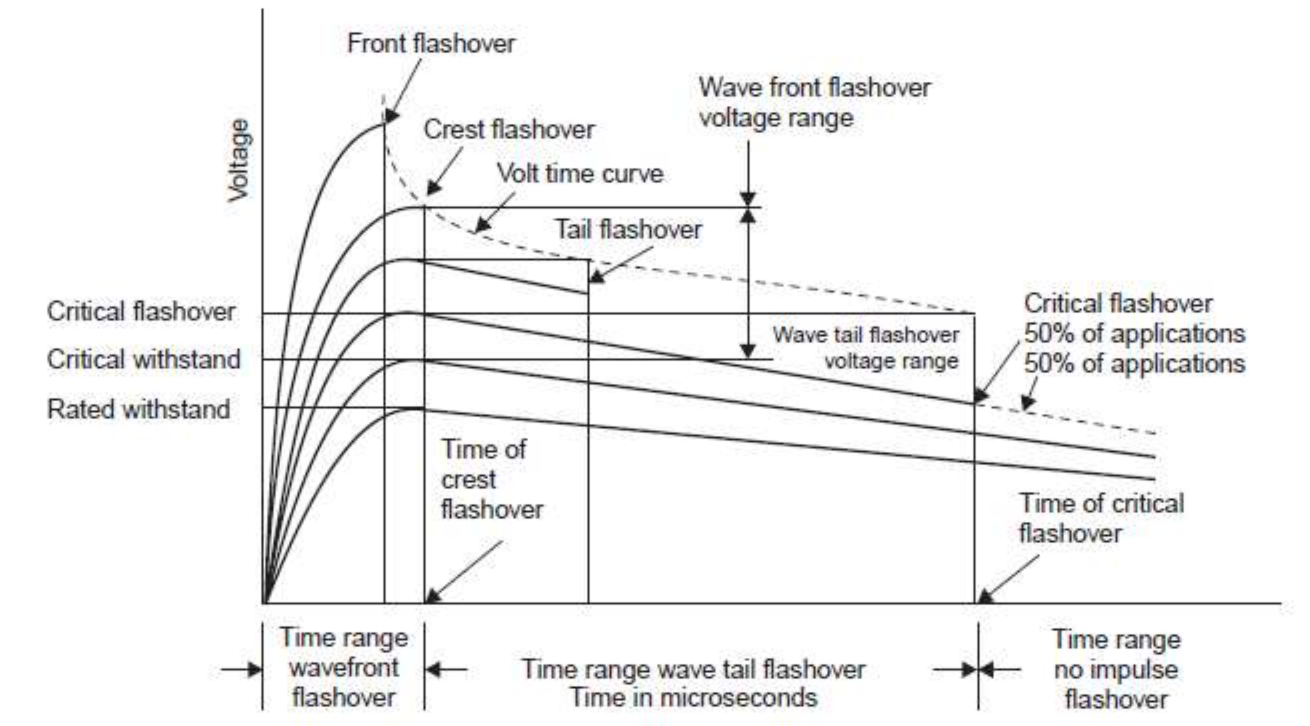
INSULATION CO-ORDINATION

Volt-Time Curve

- The breakdown voltage for a particular insulation of flashover voltage for a gap is a function of both the magnitude of voltage and the time of application of the voltage.
- Volt-time curve is a graph showing the relation between the crest flashover voltages and the time to flashover for a series of impulse applications of a given wave shape.
- Construction of Volt-Time Curve:
  - Waves of the same shape but of different peak values are applied to the insulation whose volt-time curve is required.
  - If flashover occurs on the front of the wave, the flashover point gives one point on the volt-time curve.
  - The other possibility is that the flashover occurs just at the peak value of the wave; this gives another point on the *V-T curve.*
  - The third possibility is that the flashover occurs on the tail side of the wave.

INSULATION CO-ORDINATION

- To find the point on the *V-T curve, draw a horizontal line from* the peak value of this wave and also draw a vertical line passing through the point where the flashover takes place
- The intersection of the horizontal and vertical lines gives the point on the *V-T*



INSULATION CO-ORDINATION

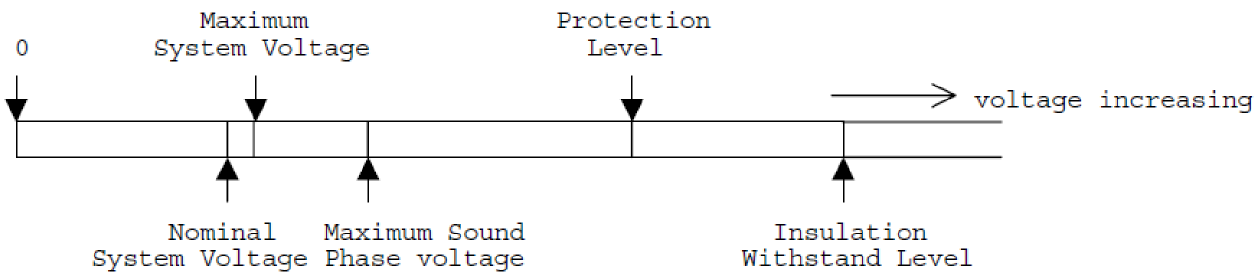
Steps for Insulation Coordination:

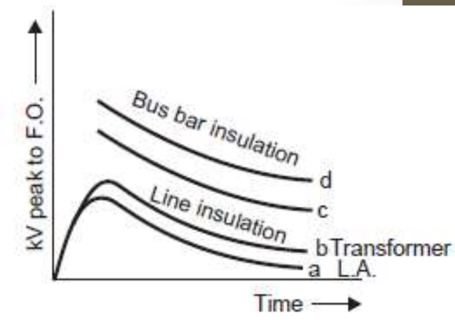
1. Selection of a suitable insulation which is a function of reference class voltage (*i.e., 1.05 X* Operating voltage of the system)
2. The design of the various equipments such that the breakdown or flashover strength of all insulation in the station equals or exceeds the selected level as in (1)
3. Selection of protective devices that will give the apparatus as good protection as can be justified economically

INSULATION CO-ORDINATION

Conventional method of insulation co-ordination:

- In order to avoid insulation failure, the insulation level of different types of equipment connected to the system has to be higher than the magnitude of transient overvoltages that appear on the system.
- The magnitude of transient over-voltages are usually limited to a protective level by protective devices.
- Thus the insulation level has to be above the protective level by a safe margin. Normally the impulse insulation level is established at a value 15-25% above the protective level.

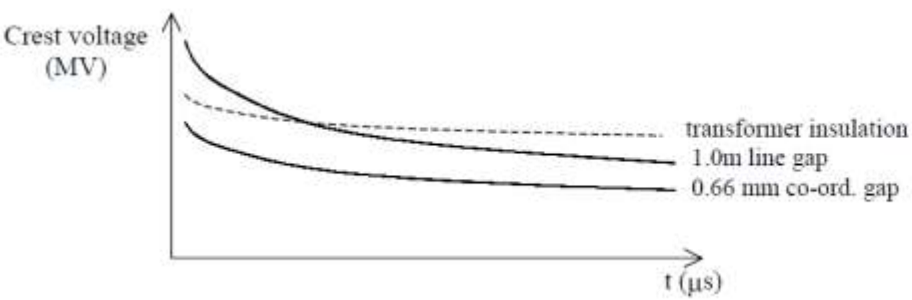




INSULATION CO-ORDINATION

Consider the typical co-ordination of a 132 kV transmission line between the transformer insulation, a line gap (across an insulator string) and a co-ordinating gap (across the transformer bushing).

former, a lightning arrester may not be used



In co-ordinating the system under consideration, we have to ensure that the equipment used are protected, and that inadvertent interruptions are kept to a minimum.

The co-ordinating gap must be chosen so as to provide protection of the transformer under all conditions. However, the line gaps protecting the line insulation can be set to a higher characteristic to reduce unnecessary interruptions.

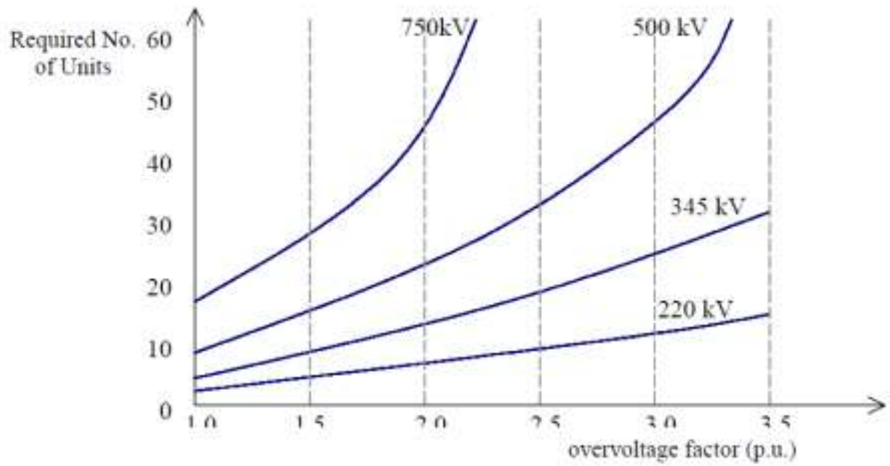
INSULATION CO-ORDINATION

For the higher system voltages, the simple approach used above is inadequate. Also, economic considerations dictate that insulation coordination be placed on a more scientific basis.

INSULATION CO-ORDINATION

Statistical Method of Insulation Co-ordination

At the higher transmission voltages, the length of insulator strings and the clearances in air do not increase linearly with voltage but approximately to $V^{1.6}$ The required number of suspensi ... is shown below.



It is seen that the increase in the number of disc units is only slight for the 220 kV system, with the increase in the overvoltage factor from 2.0 to 3.5 ,but that there is a rapid increase in the 750kV system.

INSULATION CO-ORDINATION

Thus, while it may be economically feasible to protect the lower voltage lines up to an overvoltage factor of 3.5 (say), it is definitely not economically feasible to have an overvoltage factor of more than about 2.0 or 2.5 on the higher voltage lines.

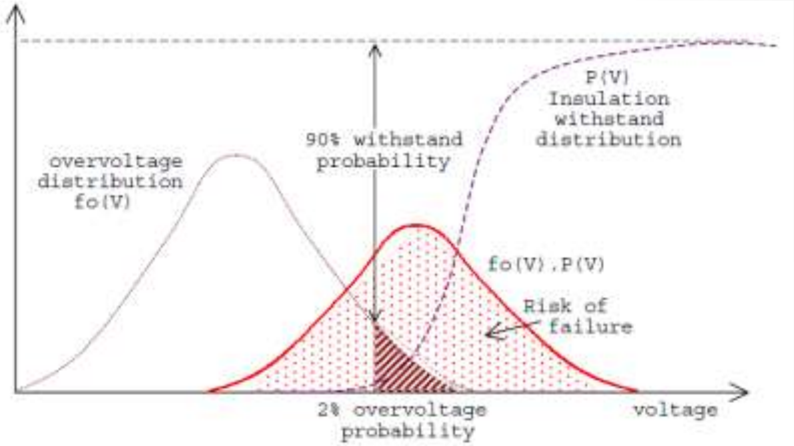
Switching overvoltages is predominant in the higher voltage systems. However, these may be controlled by proper design of switching devices.

In a statistical study, the statistical distribution of overvoltages has to be known instead of the possible highest overvoltage.

In statistical method, experimentation and analysis carried to find probability of occurrence of overvoltages and probability of failure of insulation.

INSULATION CO-ORDINATION

The aim of statistical methods is to quantify the risk of failure of insulation through numerical analysis of the statistical nature of the overvoltage magnitudes and of electrical withstand strength of insulation.



The risk of failure of the insulation is dependant on the integral of the product of the overvoltage density function $f_0(V)$ and the probability of insulation failure P(V).

Thus the risk of flashover per switching operation is equal to the area under the curve $\int f_0(V) * P(V) * dV.$

Since we cannot find suitable insulation such that the withstand distribution does not overlap with the overvoltage distribution, in the statistical method of analysis, the insulation is selected such that the 2% overvoltage probability coincides with the 90% withstand probability as shown.

Surge Arresters : Modern Surge arresters are of the gapless Zinc Oxide type. Previously, Silicon Carbide arresters were used, but their use has been superceeded by the ZnO arresters, which have a non-linear resistance characteristic. Thus, it is possible to eliminate the series gaps between the individual ZnO block making up the arrester.

Selection Procedure for Surge arresters:

1. Determine the continuous arrester voltage. This is usually the system rated voltage.
2. Select a rated voltage for the arrester.
3. Determine the normal lightning discharge current. Below 36kV, 5kA rated arresters are chosen. Otherwise, a 10kA rated arrester is used.
4. Determine the required long duration discharge capability.

For rated voltage < 36kV, light duty surge arrester may be specified.

For rated voltage between 36kV and 245kV, heavy duty arresters may be specified.

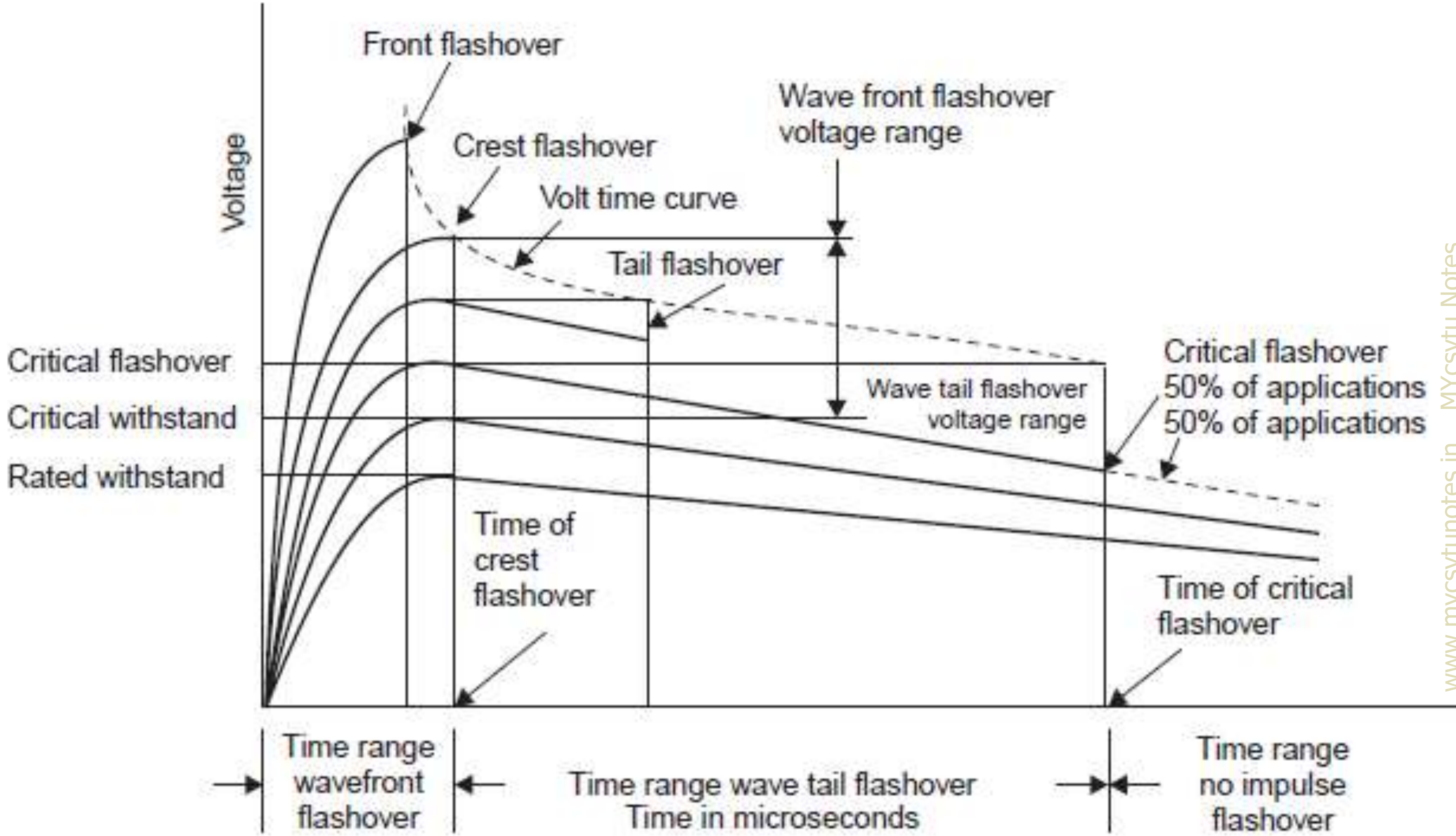
For rated voltage >245kV, long duration discharge capabilities may be specified.

5. Determine the maximum prospective fault current and protection tripping times at the location of the surge arrester

and match with the surge arrester duty.

6. Select the surge arrester having porcelain creepage distance in accordance with the environmental conditions.

7. Determine the surge arrester protection level and match with standard IEC 99 recommendations.


Front flashover
Wave front flashover
voltage range
Crest flashover
Voltage
Volt time curve
Tail flashover
Critical flashover
Critical withstand
Rated withstand
Wave tail flashover
voltage range
Critical flashover
50% of applications
50% of applications
Time of
crest
flashover
Time of critical
flashover
Time range
wavefront
flashover
Time range wave tail flashover
Time in microseconds
Time range
no impulse
flashover